



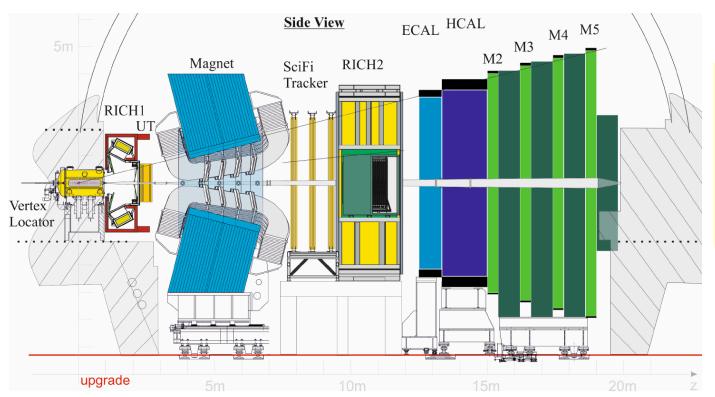


LHCb: Status, Upgrades & Results



LHCb

- World wide membership, 960 authors
- Current data 3/fb at 7 TeV, 6/fb at 13 TeV
- Upgrade I detector being installed now



Delayed by Covid.
Data rate up by
factor of 5,
Additional x2 for
purely hadronic
triggers

Not shown: purely software trigger using online calibrations



Detector highlights

- Forward direction has largest b cross-section & correlated bb acceptance. Large **p** even with small p_t, so b's go far: a few cm
- Production

 of b vs b

 at LHC

 Here B (rad) 1

 Here B (rad) 1
- Geometry permits excellent particle ID with two Cherenkov's, muon filter & ECAL
- Excellent decay time resolution ~45 fs in most modes
- Excellent charged particle tracking



Upgrade II

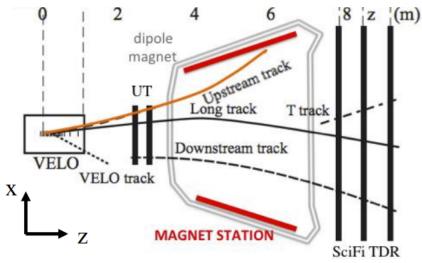
- An additional increase of integrated ∠ by
 ~300/fb, maintaining purely software trigger
- Inclusion of precision timing measurements
 ~30 ps in all critical detector elements
- Improvements in the EM calorimeter including segmentation and timing
- New VELO, UT etc...
- Also, but separate from Upgrade II: Codex-b, searches for Long-Lived Particles

[arXiv:<u>1911.00481</u>]



Upgrade Ib

- In next major shutdown
- Shorten Scifi fibers & add silicon pixels in central region to increase efficiency
- Add chambers on magnet sides to catch low p particles

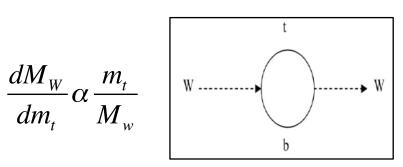




Main goal

- To find Physics beyond the Standard Model (SM), called NP, using the quantum interference induced by heavy as yet unknown particles
- Not a new technique:
- M_w changes due to m_t

$$\frac{dM_{W}}{dm_{t}} \alpha \frac{m_{t}}{M_{W}}$$



M_w changes due to m_H

$$\frac{dM_{W}}{dm_{H}}\alpha - \frac{dm_{H}}{M_{H}} \qquad \qquad W$$

b & c decays probe energy scales up to 10⁴ TeV



Reasons for NP

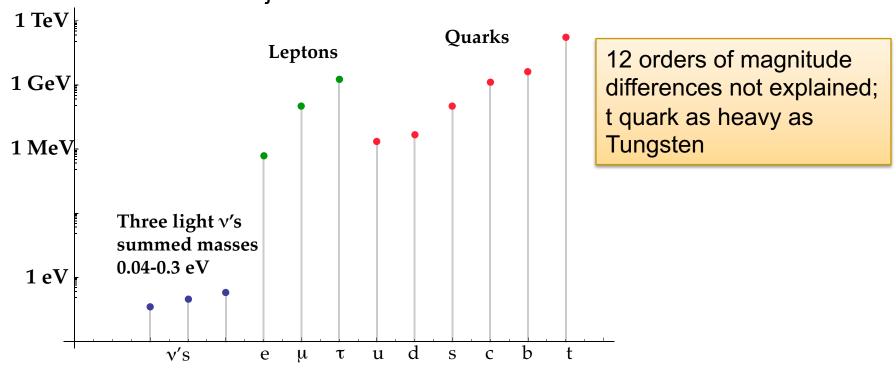
- Hierarchy Problem: Instability of the Higgs mass due to quantum corrections due to difference from ElectroWeak scale of ~100 GeV to Planck scale of 10¹⁹ GeV
- What is dark matter? Dark energy?
- Flavor problem: Why 3 replications of q's & ℓ's?
- Baryogenesis: According to Cosmology, the amount of CP Violation observed thus far in the quark sector is too small:

 $(n_B - \bar{n}_B)/n_y = \sim 10^{-20}$ but $\sim 6x10^{-10}$ is needed. Where?



More Reasons for NP

 To explain the values of fundamental quark couplings, V_{ii}, (also for neutrinos)



Explain the masses of fundamental objects: quarks and leptons



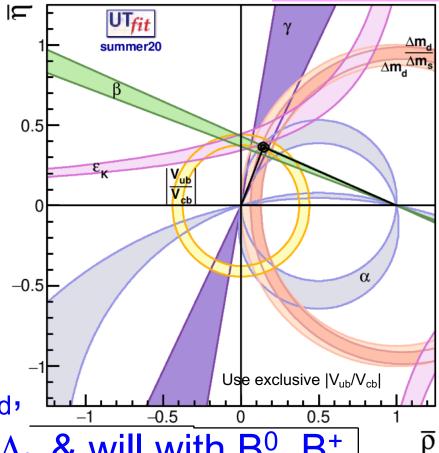
NP explorations

Can be either generic or specific

γ best measuredby LHCb

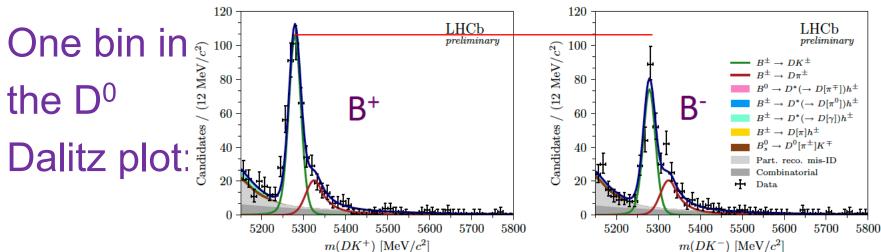
- Example of generic:
 - 4 parameters of CKM
 - **n** matrix: λ , A, ρ, η; λ =0.22,
 - A~0.8. Use different measurements to find ρ , η if they agree. If they do not, then NP!
- LHCb measures γ , β , $\Delta m_{s,d}$,

 $|V_{cb}|=A\lambda^2$, $|V_{ub}/V_{cb}|$ with $B_s \& \Lambda_b \& will with <math>B^0$, B^+



y 4 measurement

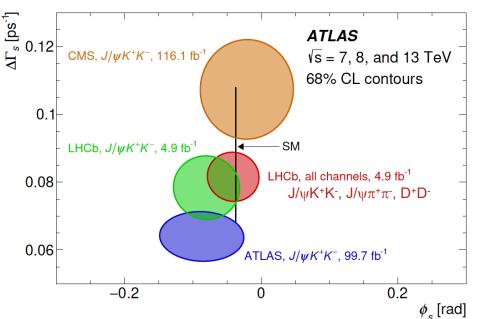
- No discernable theoretical error
- Best method: $B^- \to \overline{D}{}^0 K^-$, $\overline{D}{}^0 \to K_s \pi^+ \pi^-$. Exploits CV violating interference between $b \to cW^-$, $W^- \to us$, & $b \to uW^-$, $W^- \to \bar{c}s$ decays
- Latest result LHCb-CONF-2020-001

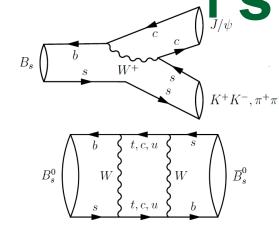


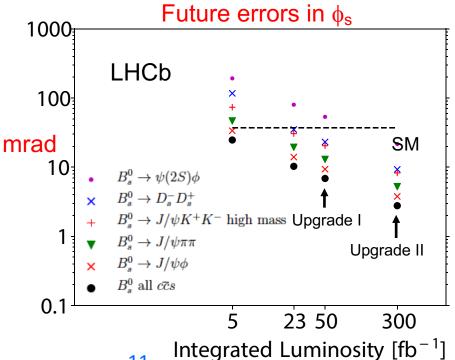
 $\gamma = (69\pm5)^{\circ}$, statistical uncertainty dominates

loops:

- Sensitive to new particles Decay + mixing diagrams
- SM prediction = -35.4±1.2 mr
- NP can replace W



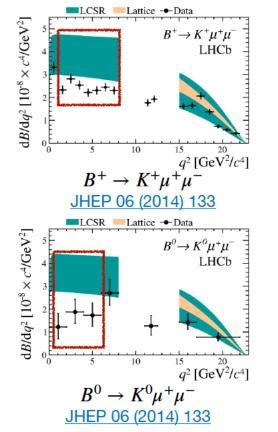


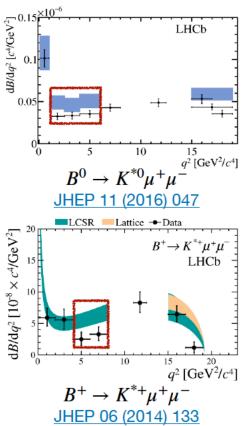


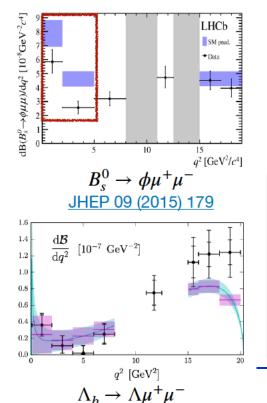


b→hµ⁺µ[−]

- Allows NP interference. In SM:
- Can test for Lepton Flavor Universality
- 1st look at b \rightarrow h $\mu^+\mu^-$ at low q²=m($\mu^+\mu$)







JHEP 06 (2015) 115

All data lower than theory, but theoretical accuracy is an issue

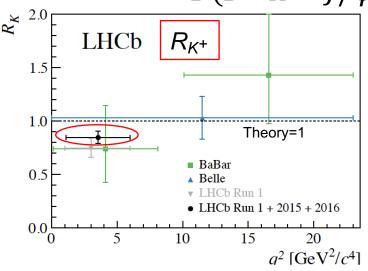
 W^-

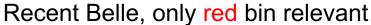


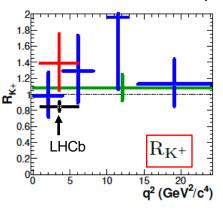
R(K) & R(K*)

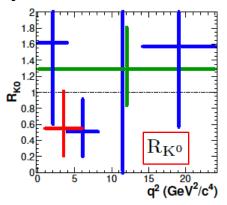
Use double ratios to reduce uncertainties:

$$R_{K(*)} = \frac{B(B \to K^{(*)} \mu^{+} \mu^{-})}{B(B \to K^{(*)} J / \psi(\mu^{+} \mu^{-}))} \frac{B(B \to K^{(*)} J / \psi(e^{+}e^{-}))}{B(B \to K^{(*)} e^{+}e^{-})}$$





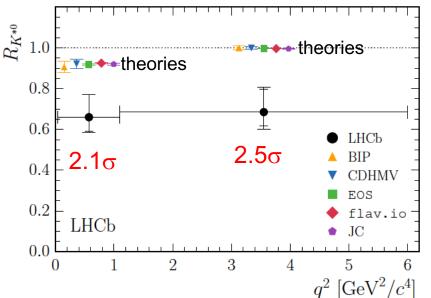


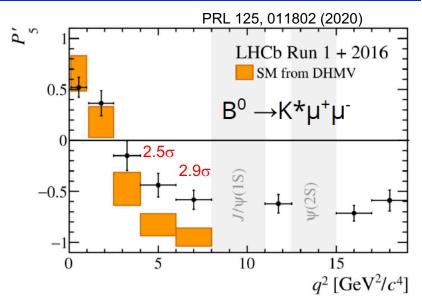


- LHCb: $R_K = 0.846^{+0.060}_{-0.054}^{+0.060}_{-0.014}^{+0.016}$ 2.5σ
- Not confirmed by Belle but large errors



R_{K*} & angular analysis

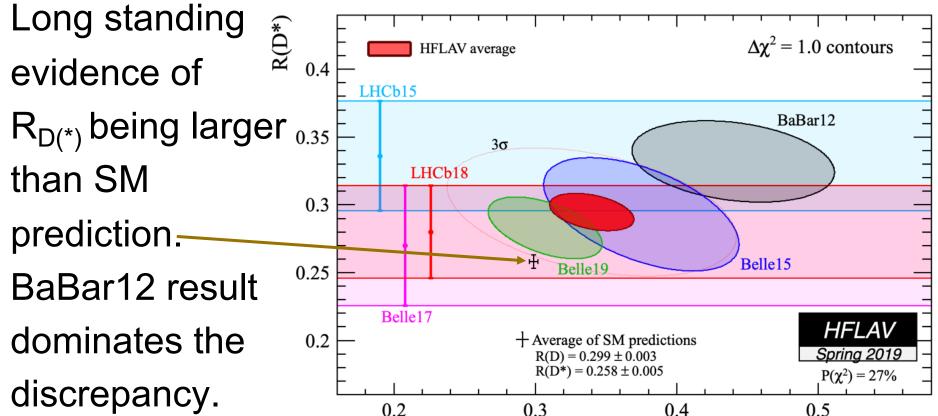




- All can be explained in SM effective field theory (SMEFT) by having having C₉~-1 instead of 0.
 See for example: Aebischer et al, Eur. Phys. J. C (2020) 80
- Could be caused by a leptoquark, or possibly a Z'



$$R_{D}^{(*)} = \frac{B(B \to D^{(*)}\tau^{+}v)}{B(B \to D^{(*)}\mu^{+}v)}$$



Can incorporate into SMEFT & is compatible with other anomalies. LHCb has only measured $D^*\tau v$ thus far, is working on $D\tau v$ & adding data to $D^*\tau v$

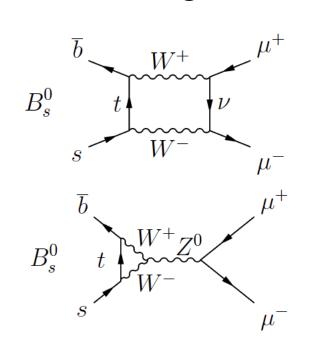
R(D)

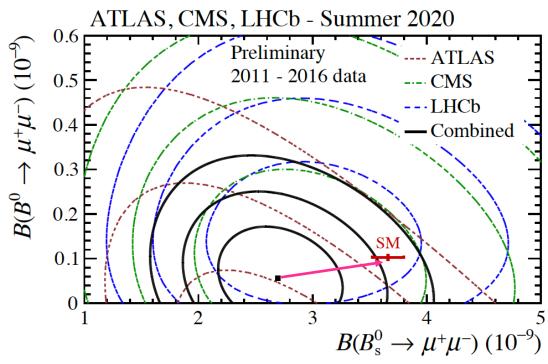


$B_{s(d)} \rightarrow \mu^{+}\mu^{-}$

SM diagrams

LHC combination



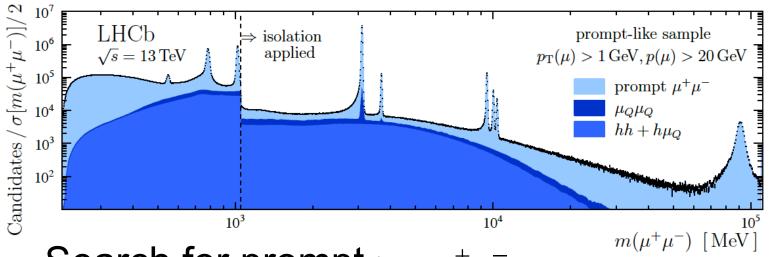


Some difference with SM ~2.1σ in direction expected by if B → h μ⁺μ⁻ deviations are real. See LHCb-CONF-2020-002



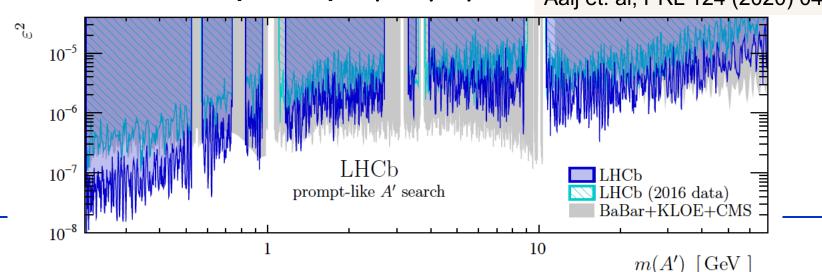
Dark y searches

LHCb very good on dimuons



Search for prompt γ→μ⁺μ[−]

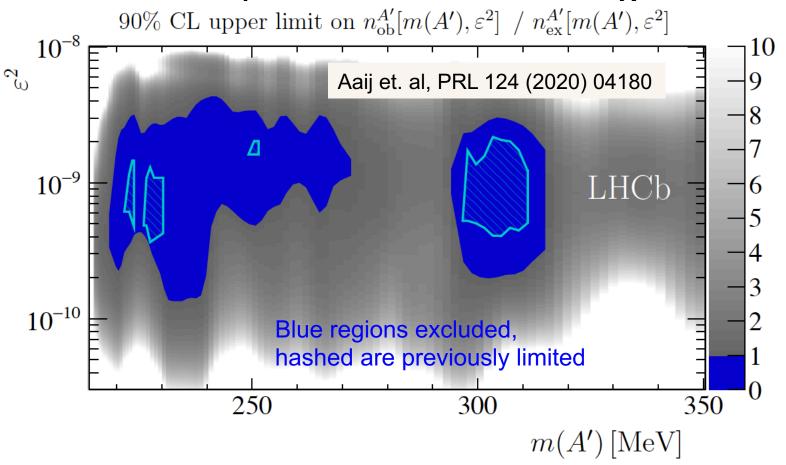
Aaij et. al, PRL 124 (2020) 04180





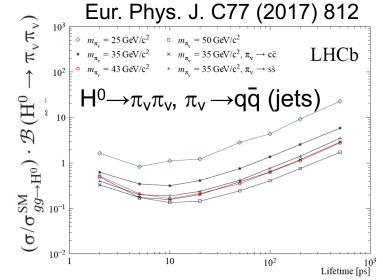
Dark y

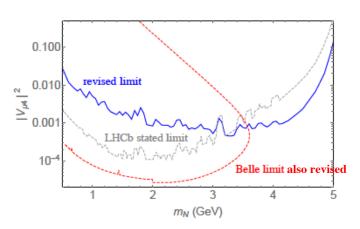
■ Here for displaced vertices ⇒ long lifetimes



Many other BSM searches

- A few examples:
- Single long lived particle decaying into jet pair
- B⁰→K⁺ $\pi^-\chi$, $\chi \to \mu^+\mu^-$, with χ having finite lifetime
- Search for Majorana ν 's $B^- \rightarrow \mu^- m_N$, $m_N \rightarrow \pi^+ \mu^-$ with 3/fb. $\pi^+ \mu^-$ pair can have finite τ . Limits revised by





Shuve & Peskin [PRD 94, 113007 (2016)]. LHCb Update coming

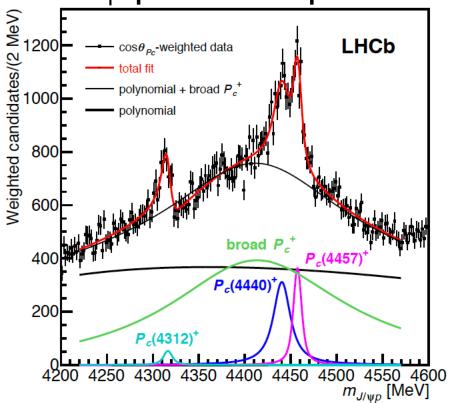
LFV: B⁻→K⁻τ⁻μ⁺

- B^{*0}_{s2}→K⁺B⁻, Γ=1.5 MeV, provides an extra kinematic constraint, allows detection of decays with a missing particle [arXiv: 1402.4205], ~1% of B⁻ production
- Here treat τ as missing, require just a charged track nearby from its decay
- Find B(B⁻ → K⁻τ⁻μ⁺) < 3.9x10⁻⁵ at 90% CL [JHEP 06 (2020) 129]
- Slightly worse than BaBar, but much larger data samples will be accumulated
- Also limits on B_(d,s)→τ[±]μ[∓], ~few x10⁻⁵

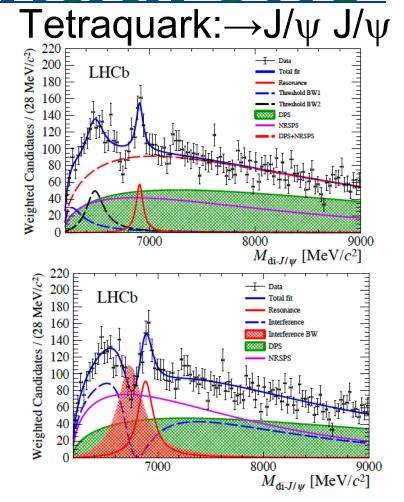


Exotic hadrons

J/ψ p Pentaquarks



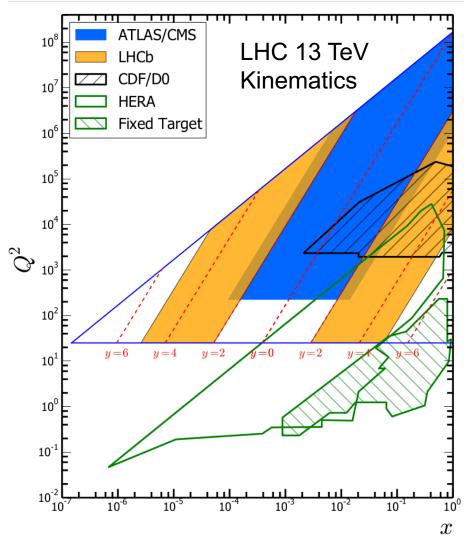
Plus many, many others





Other studies

- Cross-sections
 measurements of W, Z,
 jets & t-quark
 production, etc. in the
 forward region
- Fixed target p gas interactions using SMOG
- Heavy ion collisions
- 1st measurement of direct CPV in D⁰ decay





Conclusions

- LHCb will continue to publish excellent results from our current data & the next 50/fb to be accumulated with Upgrade I. Perhaps NP will be proven soon?
- European Strategy for Particle Physics (2020) (ESPP): "The full physics potential of the LHC and the HL-LHC, including the study of flavour physics and the quark-gluon plasma, should be exploited" [CERN-ESU-013]
- LHCb is working on Upgrades Ib & II (300/fb), essential to continue flavor physics in the HL-LHC era. US participation is crucial

The Sud